EFFECT OF AGRICULTURAL PRACTICE ON THE SOIL FAUNA

WOLFGANG TISCHLER

Zoologisches Institut der Christian-Albrechts Universität, Kiel

The effect of agricultural practice on the soil fauna is best recognized by comparing grassland and arable fields. To study the influence of ploughing one has to consider among other things the climatic area, because maxima and minima of animal populations differ in arid and humid regions. In the latter, earthworms, myriapods and wireworms have minima in summer and winter, maxima in spring and autumn. The population curves of mites and Collembola depend to a large extent upon the time of cultivation; nematodes are less influenced by the working of the soil. Earthworms suffer most when, after ploughing in autumn, frost arrives too early. Ploughing in spring reduces especially those Carabid beetles which hibernate as adults, while the larval hibernators are less affected. Not only the time of ploughing but also the type of ploughing implement can influence the edaphon. After one year of investigation it was shown that the deeper working ploughs favoured the soil animals more than the surface scraping ones. Furthermore, moleboard or disc ploughs spared the animal life of the soil more than did rotary cultivators. After the investigation plots were treated for four years with the same ploughing equipment and soil samples were taken again. The analysis showed that the differences in population density had been made up. This was explained by the abnormal weather in 1954; the very rainy summer had reduced myriapods and mites on all field plots while the number of earthworms everywhere had reached the highest possible maximum. Only the Collembola were less affected by this weather; they were more numerous on the shallow ploughed plots. By fertilizing with organic manure the edaphon increases considerably. Even fertilizing with minerals improves soil life by its indirect effect upon the vegetation cover and the increased plant refuse. The specific dung fauna remains in the dung, even if it is worked into the soil. The stimulation of the true edaphon begins some months later after the humidifying process has advanced. Winter crops make possible a rich biotic community on the surface of the ground; summer crops and, above all, leafy vegetable crops are characterized by the impoverishment of their animal populations because of the disturbance of the fields in spring. The population curves on grain fields show one maximum before mowing and a second in November/December; the population curve of surface animals on leafy vegetable fields has an initial maximum in spring before cultivation, a second before harvest and a third in November/December.

CULTIVATION OF THE SOIL AND THE EDAPHON

It is the purpose of cultivation to create a good tilth, that is, a favourable relationship between the soil particles and the pore

cavities around them. The pore cavities are partly filled with air and partly with water, an ideal soil consisting of 50 per cent solid, 25 per cent air and 25 per cent water by volume. In the course of the year not only do the proportions between air- and water-filled cavities vary continually, but the total pore volume expands in dry and contracts in moister periods. One must bear these facts in mind because every part of the soil structure is inhabited by different animals and therefore, in each case, according to the environmental conditions, especially weather, one or the other species may be favoured or not favoured. Inhabitants of the water pores include protozoa and nematodes; the air-filled cavities are inhabited by mites, Collembola and Symphyla. Finally there are animals which push or eat their way through the soil, such as earthworms and Enchytraeids, myriapods and insect larvae, of which white-grubs and wireworms are the best known.

Cultivation of the soil may be accomplished either by turning the soil over (in the course of which the original surface comes to rest beneath) as with the moleboard plough, or by causing an irregular mixing, loosening and crumbling of the soil by means of rotary or tined cultivators and harrows. Naturally such a forceful interference with the natural structure of the soil must also have its effect upon the latter's living community. The old cavities are partially destroyed and, particularly if the earth was too wet during ploughing, compact masses of earth are formed which dry to form hard clods. The water-retaining capacity and the capacity for heat-conduction in freshly worked soils at once become more unsatisfactory and more unfavourable for living creatures. On the other hand, plants are destroyed together with their root-masses and are subjected to a more rapid rotting, which is of benefit to a large part of the edaphon. A comparison between fields and their headlands, in relation to the structure of the soil particles, reveals that the soil flora must have already changed markedly for it is the plant microbes which undertake a sort of living development of the soil and make the particle-structure in the headlands more stable than in the tilled fields. To what extent the animal edaphon is influenced by the cultivation of the soil can best be seen by a comparison of neighbouring arable land and meadows (FRANZ, 1949).

First of all we must, of course, take into consideration the climatic area in which such comparative research is undertaken. The animal components of the soil population of grassland show, at least in many groups, in humid areas a summer maximum, in arid areas on the other hand, a spring and autumn maximum.

The course of the fluctuation of animal populations in arable land depends upon the cultivation and use of the soil as well as on the climatically conditioned influences. A reduction in the number of animals follows each measure which is taken to cultivate the soil; the number of animals, however, can very rapidly become adjusted again as a result of the better conditions caused by cultivation and therefore this is not always entirely harmful. Only when one wishes to reconvert a tilled field to grassland does one abandon the impoverished soil to itself. In this case the activities of the living creature alone no longer suffice to maintain a stable particle structure, such as is necessary for the thriving of higher plants. After a few years, therefore, the yield from newly established meadow land sinks and the so-called ' hunger years ' set in. Only through careful improvements such as by the use of fertilizers and the like can the soil be successfully revived in the course of years and the yield increased thereby.

Both the time of ploughing as well as the type of plough can affect the animal world differently. Thus ploughing in autumn causes a sudden strong decline in almost all population curves. This is just as true for nematodes, mites and Collembola as for earthworms, Enchytraeids and myriapods. Of all these animal groups the nematodes recover most rapidly (GUNHOLD, 1954). STÖCKLI (1952) is even of the opinion that free-living nematodes are, in general, only little affected by the cultivation of the soil. If an early and severe winter follows the autumn ploughing, the increase of most of the ground animals is hindered. In spring an astonishing recovery takes place, even if the time till harvest does not suffice to enable the population to equal in density that of a meadow. The influence of cultivations on earthworms in the autumn is very distinctly noticeable. The tilling of a field and the removal of its plant cover at this time heightens the danger of ground-frost while the worms have not yet attained the necessary resistance to frost. A sufficient root cover in the ground suffices to protect the earthworms from early frost, since they in any case seek out greater depths later in order to escape the cold (HOPP, 1948). Spring ploughing of land, which was only skimmed in the autumn, also harms earthworms; they recover more slowly than many other soil animals.

We may now consider briefly the course of the population-curves for the most important soil-animal groups occurring in tilled land on the basis of research carried out in Schleswig-Holstein. Here the macro-fauna was separated from the soil particles, with the aid of a powerful stream of water, by washing out samples of soil through

three sieves of progressively decreasing mesh. The mesofauna of the air pores was extracted by means of Tullgren funnels. The experimental field had been skimmed in autumn and was ploughed in April before being planted with potatoes. The increase of centipedes and millipedes proceeded relatively continuously with a slight minimum in summer, while the decrease in earthworms, which set in after the spring ploughing, was not made up until the autumn.

With regard to the mites and Collembola, considerable differences are revealed in the development of their populations between fields with winter cereals, summer cereals and leafy vegetables. The time of sowing or planting and the period of mechanical cultivation may change the time of their maximum occurrence, especially since the micro-climate is also changed thereby. In the winter rye field, therefore, the maximum numbers of these animal groups occurred in June, in the case of summer grain in July and in the case of swede fields and permanent meadows, not until September (HAMMER, 1949). These results, which were first obtained in Denmark, were confirmed in Schleswig-Holstein (see BAUDISSIN, 1952; KRÜGER, 1953). It must, of course, be noted that the maximum for the Collembola, at least in the case of grain fields, is already attained before mowing and that at mowing a decrease of the Collembola can already be recognized.

In order to compare the effect of different types of plough, plots were ploughed with different equipment. The following types were used:

(1) a conventional multi-furrow moleboard plough;
(2) a skim plough, which only turns the surface of the soil;
(3) a disc plough with an actively rotating disc, which has the advantage that it is superior to the moleboard types in manoeuverability and economy;
(4) a 'tillmaster', in which a screw-like worm turns around a horizontal axis and reduces the earth to small pieces which it pushes aside;
(5) and (6) a rotary cultivator in which a horizontal axis is provided with several hoes. In first gear it operates at normal plough depth (plot 5) but in second gear it works only to the depth of the skim plough (plot 6). There is no furrow and the result of its operation is similar to that of a 'tillmaster'.

Thus the deeper ploughing implements (conventional plough, disc plough and rotary cultivator in first gear) which plough to a

depth of 20 cm and the surface working implements (skim plough, 'tillmaster' and cultivator in second gear) which go to a depth of about 12–14 cm stand in contrast to one another. On the other hand, ground-turning and rotary-working equipment may be compared in that the former brings the organic substance into the deeper soil and the latter distributes it more in the surface layer. Finally, one may contrast equipment which does less to disturb the soil with that which more completely turns it over. The moleboard plough and the disc ploughs are more of the 'less-disturbing' type, while the rotary cultivator and 'tillmaster' grind the earth into small pieces; they also have the disadvantage of producing muddy conditions.

The results showed first that in the case of earthworms, and to a lesser degree of the larger diplopods, purely mechanical injuries were caused by rotary cultivator and 'tillmaster', while moleboard and disc ploughs brought about no perceptible harmful effect in this respect. At the same time one must also take into consideration in which season of the year the ploughing takes place and what the weather conditions are like. As a result of an extraordinarily dry and warm October and because of the potato harvest the surface layer was found to be relatively poor in earthworms so that the rotary cultivator in second gear hardly affected them and only in first gear caused more serious injury.

If we list the results which were obtained on the experimental fields after the completion of a vegetative period, they make evident the influence of the spring and the autumn ploughing through a comparison of the number of animals on the different plots. The taking of samples extended from March to October (Krüger, 1953).

(1) Deep working, regardless of what equipment is used, favoured earthworms and Enchytraeids, but surface working favoured the chilopods. No influence of the depth of working could be perceived as far as the diplopods, Collembola and mites were concerned. These three animal groups revealed no sufficiently certain differences between the various plots so far as their population density was concerned.

(2) If the plots on which the moleboard ploughs were used are compared with those on which the rotary cultivators were used, or if one compares the effect of the equipment which disturbs ground less with that which disturbs it more, a distinctly greater effect upon the biomass of the earthworms (not of course upon their numbers) is seen to result from the former.

(3) The plot on which the 'tillmaster' was used had, in comparison with all the others, the smallest number of animals.

To summarize, therefore, the deep-working moleboard and disc ploughs showed themselves as favourable and the surface working 'tillmaster' and rotary cultivator as unfavourable to animal life.

The experimental plots were repeatedly cultivated for four years, using the same equipment and the following rotation of crops: potato, winter rye, beet-seed and summer barley. On 15 September 1954 several samples were taken to see whether the tendency observed above still prevailed after the first year of investigation or had possibly become accentuated or, again, whether any compensation had taken place. The mowing of the summer barley had taken place on 8 September. The field had been skimmed, but a sufficiently broad strip of stubble-field remained for sampling. It must, however, be said before an opinion with regard to the results is expressed, that the weather in 1954 was quite abnormal. An unusually wet summer and autumn followed an extraordinarily dry spring. The solid-content of the soil with its 55–59 per cent was higher than at the same season in 1951 when it was 43–47 per cent; likewise the water volumes were considerably higher and the air volumes correspondingly lower. Thus for the inhabitants of the air-pore system unfavourable conditions had occurred.

The analysis of the samples gave the following results: the wealth of earthworms was astonishing; there was a density on the average of 400 specimens per m^2 up to a depth of 30 cm, of which the overwhelming majority was located in the top 10 cm. The count was four times higher than the plots had shown three years previously when they carried potatoes. They even surpass such figures as have been recorded for the best grassland. No superiority of deep-working over surface-working equipment, of ground-turning over rotating disc types, or of less disturbing ploughs over those which break down the clods of earth more completely, could be observed. The 'tillmaster' plot this time even took first, and the conventional plough plot the last place, but the differences are too small to permit a statistical confirmation of the results. Enchytraeids were not investigated again, since OVERGAARD NIELSEN (1953) has shown that these worms must be extracted by a special method (see page 365) and only a small proportion of them is obtained by simple washing and sieving.

The number of Chilopoda and Diplopoda had decreased considerably. It was ten times less than three years before, so that no conclusions can be drawn for differences in density between the various experimental plots. The number of mites and, to a lesser extent, of Collembola was also much lower than on 15 September 1951 and it must be considered here that their decrease

in the case of summer grain takes place earlier than is the case with potatoes (with which the field was planted in the first year of investigation). Nevertheless, on 15 September 1954, about 8,000 Collembola and 4,000 mites per m^2 of surface down to a depth of 28 cm were counted in comparison with 15 September 1951, when the corresponding figures amounted to 15,000 and 56,000.

While, in the case of the mites, no unambiguous relationship between the various ploughing treatments could be perceived, in the case of the Collembola a clear superiority of the surface-working in contrast to the deep-working ploughing equipment was apparent. Especially animated by all groups of soil animals was the plot which was worked with the 'tillmaster'; it showed moreover the greatest number of Symphyla.

What conclusions may be drawn from these investigations which have, it is true, consisted of analysis of relatively few samples ?

(1) A clear superiority of one type of plough under all circumstances and for all animal groups is not so far apparent.

(2) The influence of weather may be stronger than that of the different methods of cultivation. Extraordinary precipitation and moisture brought about such a pronounced reduction in the numbers of diplopods, chilopods and mites that their populations had to build themselves up again and certain differences may easily be eliminated as a result of this. Earthworms, on the other hand, can in such years be so favoured that a recession caused by cultivation is easily compensated and differences caused by various types of ploughing equipment likewise do not come into play.

(3) In arid and humid areas the effect of different types of ploughing equipment upon the animal life might very probably be different so that the results cannot be transferred without caution from one country to another.

(4) Among the soil animals of arable land in humid areas the earthworms have far and away the greatest significance. The Collembola, which are less sensitive than mites and myriapods to extreme weather conditions, are second in importance.

So far we have not yet discussed the insects, with the exception of the Collembola, although the larvae of flies and beetles as well as the beetles themselves play a great part in the biotic community of the soil. Since, however, most of them have only one generation per year and pass only certain phases of their life in the soil and frequently are deposited in the soil as eggs only after cultivation, it is not to be wondered at that a proven influence on them of different types of ploughing equipment or of ploughing in general cannot

always be recognized. In the case of wireworms with their longer period of development the situation is different. They have, in general, in our climate a minimum in the summer and a maximum from autumn to spring, while they spend the winter at a greater depth. A recovery of the population after the summer only takes place in grassland and not in arable land. After the ploughing of grassland and subsequent cultivation the decrease not only continues but becomes greater from year to year. The lack of plant covering in summer or only a partial plant covering kills eggs and young larvae; the upper layer of the ground becomes too dry and in spring, the period of maximal activity, there is a lack of nourishment for them in the fields (Ross, Stapley and Cockbill, 1947); this is true above all for the summer cultivation.

Corresponding influences upon white-grubs can also be determined. For oviposition chafer beetles in no way, as was hitherto generally supposed, prefer a soil covered with vegetation, but they will also lay their eggs in the open vegetable fields although the grubs of the first instar soon die as a result of unfavourable food and moisture conditions (Ehrenhardt, personal communication). Consequently the rotation of crops can strongly influence the life of insect larvae which have a protracted development. *Corymbites aeneus* (L.) for example, a characteristic species of Elaterid on light soils, is disturbed as a full-grown beetle at the time of oviposition when a field is prepared in spring. The long rest with winter cereals does not affect the fully grown beetle. On the other hand, leafy crops later favour the larvae since the food conditions in the potato field are better than in a rye field which has been harvested earlier and skimmed (Heydemann, 1953).

In the case of the Carabid beetles we find distinct differences in the degree of damage caused to them by the spring cultivations. The species with hibernating larvae and which exist as adults from summer to autumn escape harm caused by cultivation more easily than do such species as hibernate as fully grown beetles. The beetles which are found on the fields in the spring are much more sensitive to being covered with earth than are larvae which live in the soil. Therefore it is especially among the larval hibernators lying in the subsoil that we find many of the insects which are characteristic of vegetable fields.

We see here that we must now really proceed from group ecology to autecology in order to be able to make reliable statements. This is true not only for insects but also for myriapods, mites and earthworms. The abundance of the same species is quite different, for example, in cultivated fields and grassland.

Finally in this connexion one point might still be mentioned which is of interest regarding plant protection. If multi-furrow ploughs are used, a large proportion of soil-insect larvae no longer comes to the surface but is immediately covered over again. For example where a triple-furrow plough is used 40 per cent of the insects in the furrows are immediately covered. Where a single-furrow plough is used, birds have about 24 hours time per hectare for picking up the insects in the furrows which have been ploughed; this time is decreased to six hours where a two-furrow tractor plough is substituted and to four hours where a three-furrow plough is used (RADEMACHER, 1954).

FERTILIZERS AND THE EDAPHON

Fertilizing takes effect not only upon plant growth but influences all the biotic communities of the fields. This is true directly of fertilizing with organic matter and indirectly of fertilizing with minerals—if we merely consider the animal world.

Fertilizing with minerals stimulates the activity of the plant microbes of the soil and accelerates by this means the decomposition of organic substances and the whole interchange of matter. The animal life of the soil is stimulated indirectly through the increased plant growth and plant refuse resulting from the latter. This is true not only for the larger animals but also for nematodes (Stöckli, 1952), the mites and the Collembola (Franz, 1953).

The increase of the edaphon proceeds more intensely and more rapidly by means of fertilizing with organic manure. It affects all groups of organisms. First, with the manuring, a fauna is introduced into the ground which is quite peculiar to the dung and which differs considerably from the soil fauna proper. As a result of the more specialized conditions prevailing in the dung the number of its species is of course smaller, but the number of individuals and the biomass is much greater. Just as is the case with the soil, the surface in manure is the most densely populated. The process of decomposition gradually proceeds towards the centre of the manure pile. In this connexion Collembola, the dipterous larvae and the earthworm *Eisenia foetida* (Sav.) are especially important in addition to the microflora. Oribatid mites and Enchytraeid worms occupy quite a subordinate position. Among the mites the predatory Parasitiformes predominate and among the beetles the Staphylinidae (FRANZ and REPP, 1949).

It is obvious that the transfer or change of a large heap of manure into smaller piles on the field brings about a more regular decomposition of the mass of manure so that the innermost part is

sufficiently decomposed before the surface areas have undergone too great a loss of substance by means of excessive decomposition. If one transfers the outer layer of a large pile suddenly to the interior the whole process of decomposition can cease. During the winter the stercoral animals retain their activity by withdrawing somewhat deeper into the manure which generates its own heat. The colonization of stable manure by the typical dung fauna takes place in the manure heap from the surroundings. The process is very rapid, therefore, where colonized dung is already present (LEITNER, 1946). One to two months are necessary for the development of an active animal life in freshly heaped manure, depending upon the time of the year, the position of the manure and the nature of the underlying straw material present. In the winter more time is of course required. Stable manure which is produced in winter should only be used in the following autumn, not in the spring.

As we have already mentioned, if the manure is incorporated into the soil, its further decomposition is at first exclusively accomplished by the organisms which are peculiar to it. The organisms of the soil are at first in no way activated. On the contrary, the soil which lies over and under the dung is even rather poorer in soil animals at first. This fact is especially striking where fresh dung is used. Only after extensive humifying of the ploughed-in manure several months later does an advancement of the living organisms in the soil take place. In this connexion the depth at which the manure has been put is of importance. When it was buried 15 cm deep its biological effect upon the edaphon was more unfavourable than at 5 to 10 cm; the oxygen and carbonic acid conditions being probably responsible for this. The actual amount of the manure seems to be less important for the soil organisms. Only in the case of fresh material is an excess unfavourable because then undecomposable pieces of straw accumulate in the soil. It is clear from a comparison of fertilized plots that the effect of fertilizing with organic matter which intensifies the edaphon does not last much longer than a year (Franz, 1953).

To summarize: an undisputable superiority of organically fertilized over unfertilized fields is manifest in regard to the activity of the edaphon, while surfaces which are treated with inorganic fertilizers (which have an indirect effect) occupy a middle position. The investigations of MORRIS (1927) in England and Franz (1949, 1953) in Austria have shown this quite distinctly.

With the gradual decomposition of the organic manure the dung fauna changes into a true soil fauna through the intermediate stage

of compost fauna. Here we have to do with metabiotic processes in which one series of organisms provides the conditions of life for the one following it. Each phase of the animal component is thus closely bound up with the microflora. The careful analysis of species of Collembola which were previously regarded as having a wide tolerance has shown that the question is actually one in which the species are specialized in regard to certain phases of rapidly changing micro-milieu as, for example, in compost (GISIN, 1952). The numbers of animals in compost is enormously high. Per m^2 surface down to 10 cm deep 50,000 to 150,000 Enchytraeids have been observed, 300 earthworms, 33,000 insects and their larvae, 130,000 Collembola, more than 300,000 mites and several millions of nematodes (Gunhold, 1952; GRAFF, 1953). The reproductive activity of earthworms particularly is influenced by the type and the amount of the organic substance (EVANS and GUILD, 1948).

MANNER OF CULTIVATION AND THE EPIGAION

The manner of cultivation of the fields affects also the surface fauna. Here, the long rest which results from the winter-cultivations permits an undisturbed development of the animal population, where the peak in the case of grain fields occurs about June. Leafy vegetable fields, on the other hand, are disturbed by cultivation in spring and later at precisely the time at which many species return from the refuges of the surrounding area and when the animal life of the field begins to become stabilized. Therefore, winter crops make possible a very rich biotic community; summer crops, especially leafy vegetables, are characterized by the impoverishment of the fauna.

From a qualitative standpoint one can view leafy fields as fragmentary variants of the winter crops which thrive in the same soil. Nevertheless, some species of animal are favoured by the displacement of the vegetative period (such as happens with crops of beets and potatoes) into the late summer or early autumn (Heydemann, 1953). Here it primarily affects species with an imaginal stage bound to the later season of the year so that they do not develop to the same extent on winter crops because of the early harvest. As we have already mentioned in the case of the methods of cultivation, it is above all the larval hibernators among the Carabid beetles which remain in the larval stage until early summer and are therefore less harmed even by the spring cultivation of fields. The beetles which hibernate as adults (for example *Carabus auratus* (L.)) suffer, for the most part, death by burial. Moreover the larger beetle

larvae of the Carabidae, Staphylinidae and Cantharidae are more reduced in the spring by field operations than are the smaller ones. Several species have two generations a year and the Carabid *Amara fulva* (Doy.), which lives on light soils, will serve as an example. Its first generation occurs in grain fields while the second develops best in the potato fields. The proximity of the two crops with their different vegetative peaks therefore furthers the abundance of this species. Other animals are also characterized by an interchange between agricultural land employed in different ways, as for example the *Sitona* weevils or the field voles which are prone to colonize fields of perennial leguminous crops, such as clover or lucerne, after the annual crops have been harvested.

In all research concerning the animal life of the fields one must also consider the differences in population between the margin and the middle of the field. The lesser yields of the margins of fields are known to the agriculturalist and the increased amount of light and heat at the edges of the fields increases the development of weeds there. Pronounced and frequent fluctuations of temperature and moisture as well as the greater effect of the wind are unfavourable to the growth of crop plants and all these factors also affect the animal population. Insects largely proceed from their winter quarters or from the crops of the previous year inward from the edge on to a new field and spread out only gradually towards the middle. This is as true for beetles as it is for bugs, aphids and gall-midges. For the surface fauna of the soil of fields an outer zone which is a few metres wide reflects to a considerable extent the influence of the adjacent headlands, woods and hedges.

Reaping and harvest have a very decisive significance for the animal world. Large numbers of grasshoppers move on to the stubble from the adjacent headlands and meadows. Carabids, Staphylinids and spiders, which are robbed of their protective roof of vegetation and threatened by drought, take refuge as far as possible under the sheaves and after the removal of the grain they frequently return to their refuges outside the fields. Many insects of the vegetation layer still remain for several weeks on the stubble and only gradually wander away, as is the case with the grain bugs.

The ploughing of the soil brings about the second great effect. This can be especially well observed from the example of the spiders, ground-beetles and diplopods where an existence on the surface is particularly suited to the manner of cultivation. This point becomes still clearer in a comparison of grain and potato fields with the same type of soil; the displacement of the maxima of the individual species is revealed.

By considering both the density of individuals and the number of species, the same picture of the annual rhythm of the animal population in fields is obtained. Leafy vegetables have three peaks, one before planting or sowing, one at the greatest development of their growth, and a third in the winter months from November to December. Winter cereal fields, on the other hand, have only two maxima for their animal populations, one before reaping and the second in November–December, when many Staphylinidae, *Catops* species, Diptera and so forth are still active.

The rotation of crops offers one of the most interesting problems of agricultural ecology. Here, particularly, the biocoenotic viewpoint must not be forgotten. Under certain circumstances uninterrupted or too frequent cultivation of the same plant species leads to a pronounced removal of important nutrients and to a change in the composition of the microbes in the rhizosphere and an increase in the root exudate in the ground; moreover, a faulty crop rotation can favour the increase of many pests. The importance of the weed flora must also be considered for weeds act as intermediate reservoirs or hosts for many diseases and pests. However, rotation of crops in the case, for example, of a grain field which is heavily covered with wild mustard (*Sinapis arvensis*) does not lessen the species of pests from a preceding cabbage field but offers, on the contrary, further possibilities of development of the injurious organisms. Maladies which are due to insufficient rotation of crops can therefore result as a consequence of weeds, but, on the other hand, may also cause the latter to thrive since the sick crop plants need less water than healthy ones and favour weed growth in the field. Such a mutual chain-relationship of cause and effect, which is often difficult to determine, causes many difficulties in synecological research.

REFERENCES

Baudissin, F. v., 1952, Die Wirkung von Pflanzenschutzmitteln auf Collembolen und Milben in verschiedenen Böden. *Zool. Jb. (Syst.)*, **81,** 47–90

Evans, A. C., and Guild, W. J. McL., 1948, Studies on the relationship between earthworms and soil fertility. IV. On the life cycles of some British Lumbricidae. *Ann. appl. Biol.*, **35,** 471–484

Franz, H., 1949, Bodenleben und Bodenfruchtbarkeit. *Sammlung Biologie.* Vienna, **8,** 95 pp.

— 1953, Der Einfluss verschiedener Düngungsmassnahmen auf die Bodenfauna. *Angew. Pflanzensoziol.*, **11,** iii+50 pp.

— and Repp, G., 1949, Untersuchungen über die Stallmistrotte im Stapel und im Boden. *Bodenkultur*, **3,** 465–486

Gisin, G., 1952, Ökologische Studien über die Collembolen des Blattkompost. *Rev. suisse Zool.*, **59**, 543–578

Graff, O., 1953, Bodenzoologische Untersuchungen mit besonderer Berücksichtigung der terrikolen Oligochaeten. *Z. Pflanzenernähr., Düng., Bodenkunde*, **61**, 72–77

Gunhold, P., 1952, Über die im Kompost lebenden Nematoden. *Bonn. zool. Beitr.*, **3**, 151–166

— 1954, Vergleichende bodenzoologische Untersuchungen an Wald-Wiesen- und Ackerböden im pannonischen Klimagebiet. *Z. Pflanzenernähr., Düng., Bodenkunde*, **66**, 19–29

Hammer, M., 1949, Svingninger i Mikrofauna i skifter i Dansk Landsbruk. *Ann. ent. Fenn.*, **14** (Suppl.), 75–80

Heydemann, B., 1953, Agrarökologische Problematik, dargetan an Untersuchungen über die Tierwelt der Bodenoberfläche der Kulturfelder. *Dissertation, University of Kiel*

Hopp, H., 1948, The ecology of earthworms in cropland. *Proc. Soil Sci. Soc. Amer.*, **12**, 503–507

Krüger, W., 1953, Einfluss der Bodenbearbeitung auf die Tierwelt der Felder. *Z. Acker- und Pflanzenbau*, **93**, 261–302

Leitner, E., 1946, Zur Kenntnis der Milbenfauna auf Dungerstätten. *Zentralbl. Entom. Klagenfurt*, **1**, 1–48

Morris, H., 1927, The insect and other invertebrate fauna of arable land at Rothamsted. Part II. *Ann. appl. Biol.*, **14**, 442–464

Overgaard Nielsen, C., 1953, Studies on Enchytraeidae. 1. A technique for extracting Enchytraeidae from soil samples. *Oikos*, **4**, 187–196

Rademacher, B., 1954, Was bedeutet die Weiterentwicklung der Anbautechnik in Acker- und Pflanzenbau für den Pflanzenschutz. *Z. Pflanzenkrankheiten*, **61**, 177–184

Ross, D. M., Stapley, J. H., and Cockbill, G. E., 1947, Wireworm populations in relation to crop production. *Ann. appl. Biol.*, **34**, 66–103

Stöckli, A., 1952, Studien über Bodennematoden mit besonderer Berücksichtigung des Nematodengehaltes von Wald-, Grünland- und ackerbaulich genutzten Böden. *Z. Pflanzenernähr., Düng., Bodenkunde*, **59**, 97–193

DISCUSSION

Dr. E. W. Russell (from the Chair) : May not the effect of cultivation implements on soil fauna be through their effect on weeds ? Were the experimental fields free from weeds, or were they rather weedy ?

Professor Tischler: The presence or absence of weeds was taken into account, but no difference between the plots was found.

Dr. P. W. Murphy: I was very interested in Professor Tischler's results where Acarine populations were greatly reduced during wet periods. I have some observations which may have a bearing on this point. In sampling a podzol with *Calluna vulgaris* at short intervals there was a great reduction in numbers after very heavy rainfall when compared with samples taken a short period before. The group most affected was the Oribatei. The Mesostigmata numbers were too small in this habitat to draw con-

clusions. Of course the position is not as simple as this; there are additional data which indicate that some hygrophil Oribatids can withstand submergence in water for some time. In culture experiments, using a new technique, I have found that Oribatid mites can withstand this treatment. The period in this case was 12 hours though the experiment was for a very different purpose. Mesostigmata appeared to be much more sensitive and mortality rates were high, although the number of observations would not warrant a fair conclusion.

MR. J. G. BLOWER: Did the Collembola increase after rain ?

PROFESSOR TISCHLER: No, but they were definitely less affected than mites.

MR. BLOWER: Collembola are generally more hydrofuge than mites. May not this explain the difference ?

PROFESSOR TISCHLER: I should guess that there are differences in the moisture tolerance of different species.

MR. BLOWER: With regard to the population of *Cylindroiulus teutonicus* being reduced by mowing, does this imply that this is a hemi-edaphic form and not a true soil animal ? Also, since it is the commonest Iulid, are there *any* actually in the soil ?

PROFESSOR TISCHLER: *C. teutonicus* does occur in the soil. Population figures for before and after mowing were obtained by means of pit-traps and thus only the decrease of the surface forms was measured. There were always others in the soil.

MR. J. A. SVENDSEN (Zoology Department, University of Durham): Does Professor Tischler consider the number of Lumbricids, 400 per m^2, under the arable conditions discussed, to be high, by comparison with published figures for permanent pastures ? If this is so, it can be deceptive since many of the published estimates of Lumbricid populations are low as a result of poor sampling methods.

PROFESSOR TISCHLER: In meadows and pastures in Schleswig-Holstein we found 2–300 Lumbricids per m^2, while arable land usually yielded about 100.

PROFESSOR W. KÜHNELT: Did Professor Tischler detect that the composition of the micro-fauna had changed due to the cutting-up of earthworms which would thus make more carrion available as food ?

PROFESSOR TISCHLER: The micro-fauna was not identified to species level. It might be expected, however, that there would be a change in the composition of the biological spectrum if many pieces of injured earthworms came into the soil.

DR. N. H. E. GIBSON (Department of Agricultural Zoology, University of Leeds): Has Professor Tischler any information on the effect of compaction of the soil by grazing animals on the micro-arthropod fauna of pasture soils and also on the effects of rolling on the fauna of arable soils ? Statements to the effect that the trampling of grazing animals caused a reduction in the micro-arthropod fauna of the soil of grass fields were made by M. Thompson (1924, *Ann. appl. Biol.*, **11**, 349) and by J. Ford (1935, *J. Anim. Ecol.* **4**, 145).

PROFESSOR TISCHLER: There is no recent work on this subject known to me. The older references would not seem to be of much value.

MR. SVENDSEN: The jar traps used by Professor Tischler measure activity rather than population numbers, so that it is presumably possible that the population concerned decreased in activity rather than numbers.

PROFESSOR TISCHLER: It is true that the trap method measures only the population activity. There does not yet appear to exist a possibility of correlating the population activity with population density.

MR. J. HOBART (Department of Agricultural Zoology, University College, Bangor) : Did Professor Tischler carry out corresponding trapping in the hedgerows at the time that the numbers of animals was decreasing in the field traps, that is, at the time of the cultural operations ?

PROFESSOR TISCHLER: These data have been obtained over four years, but they are not yet analysed.

DR. RUSSELL: If larger soil animals migrate from the centre of the field to the headlands, would not one expect the size of field to affect the size and composition of the soil fauna ?

PROFESSOR TISCHLER : One certainly must expect that the size of field affects the size and composition of the surface fauna of those fields. Fields of very large extent, however, which could decide this point are not found in the area where investigations have been made.

DR. RUSSELL: I am greatly interested in the possibility of affecting the activity of the soil fauna through changes in methods of cultivation, but hope that we will not have to go back to the horse plough in order to control our plant pests in the soil !